U. S. Navy Operational Sea Ice Remote Sensing

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***Abstract*-The National Ice Center provides a variety of sea ice products and services. Most of these products rely heavily upon remotely sensed data. These products are briefly described in this report, with a focus on elucidating the important role that remote sensing plays in the production of these products.**

I. INTRODUCTION

In 1951 sea ice earned recognition from the U. S. Navy as a hazard to navigation when it caused severe damage to a convoy of Navy ships navigating along the west coast of Greenland during the establishment of a distant early warning station and Thule Air Base, Greenland. Most early sea ice observations were made from coastal stations, transiting ships, and aircraft patrol.

With the launch of the National Oceanic and Atmospheric Administration (NOAA), NOAA-2 satellite and the National Aeronautics and Space Administration (NASA), NIMBUS-5 satellite in 1972, it became possible for the first time to routinely observe sea ice covered regions of the globe from space. This observing system was greatly enhanced in 1978 with the launch of SEASAT, TIROS-N, and NIMBUS-7 [1, 2]. With the launch of these satellites came the dawn of modern ocean remote sensing, paving the way for future operational sea ice monitoring.

The content and scope of the National/Naval Ice Center (NIC) sea ice products has evolved over time in response to technological advances in spaceborne hardware and algorithm design [3]. In this paper we discuss the current NIC product suite within the context of the existing constellation of earth-observing, spaceborne sensors. Future plans will also be briefly discussed.

II. DATA SOURCES

Visible and infrared (VIS/IR) imagery from the NOAA polar orbiting and Defense Meteorological Satellite Program (DMSP) satellites represents the mainstay of operational sea ice analysis. The sensors carried aboard these satellites [4] have resolutions ranging from 0.55 km to 1.1 km and are available to the NIC in near real-time through the NOAA, National Environmental Satellite and Data Information Services (NESDIS). Weather permitting, the ice edge is easily detected in this imagery, and techniques have been developed to allow identification of the sea ice concentration and type (the later a proxy for sea ice thickness). Unfortunately, the polar regions are frequently obscured by clouds (~70%), thus rendering VIS/IR imagery useless. In these circumstances the NIC relies heavily upon data from passive microwave (Special Sensor Microwave/Imager, SSM/I) and active microwave, synthetic aperture radar (SAR, i.e. RADARSAT) sensors to augment its VIS/IR archive. Both sensors provide nearly all-weather coverage, but address different operational requirements. The SSM/I provides daily global coverage, but only has a resolution of ~25 km x 25 km. Algorithms have been developed to estimate the total sea ice concentration, the fraction of multiyear sea ice, and more recently the thickness of thin ice types. Many of these algorithms are routinely run at the NIC [5] (http://www.natice.noaa.gov/science); however, the low spatial resolution of these data makes it difficult to accurately identify the sea ice edge. SAR data are a superb source of information on sea ice concentration, sea ice type, and the ice edge at a resolution of 0.5 km [6]. The only significant issue with SAR data is that the data are expensive to purchase and are not available globally in near real-time.

III. NOWCAST PRODUCTS

'*Accurate knowledge of the marginal ice zone (MIZ) and pack ice location is essential for continuing submarine operations in the Arctic. ... Arctic operations remain a key component of the submarine force's flexibility to operate anywhere, anytime*.' (Commander, Submarine Forces, U.S. Atlantic Fleet)

Driven by the Navy requirement to support its submarine fleet along with the growing needs of other U.S. civilian agencies, the NIC provides a number of products and services. The primary NIC product is a hemispheric Arctic sea ice chart produced in alternate weeks. Images from the different sources are combined in a "manual" data assimilation process where the most recent and highest resolution images are analyzed first followed by a progression through other available data [7]. The final product is then compared to climatology [3] and against the previous week's chart to identify any errors or anomalies in the current week's analysis. This product is designed for strategic planning and scheduling purposes, and to maintain an ongoing assessment of the Arctic climate. However, it is not recommended for navigation purposes because, being a weekly average, it does not represent the ice conditions at a specific analysis time.

To respond directly to the tactical needs of the underway submarine fleet, the NIC produces two specialized message products. In support of the Atlantic and Pacific fleets respectively, the Special Arctic Oceanographic Synopsis (SPAROS) and the Ice Hazard Message products product are produced [8]. These messages consist of the location of the 100% ice concentration boundary, the analyzed ice edge, and the 24-h ice edge forecast. RADARSAT is the sensor of choice for producing this product, because of its all-weather capability and its high spatial resolution. However, when RADARSAT data are unavailable, other available data sources are used to complete the product.

The NIC also produces a Fractures/Leads and Polynyas (FLAPS) product as well as annotated imagery. Leads are oriented and often extended openings within the sea ice that can be used for surface transit. Polynyas are recurring open-water regions within the pack ice. The FLAP product is produced by request and provides information detailing the locations and orientations of features within the sea ice that are suitable for submarine surfacing. Annotated images are provided for non-routine, special exercises. Bandwidth limitations preclude sending these images directly to submarines at sea, but shore staff routinely use them for planning purposes.

IV. FORECAST PRODUCTS

Good long-term and short-term forecasts of sea ice conditions are also necessary for safe operations in ice covered waters. Recent research has raised concerns that at some date in the foreseeable future, the Arctic may become ice-free for at least part of the summer season [9, 10]. On the basis of this research, the Office of Naval Research, the Naval Ice Center, and the Arctic Research Commission [11, 12] sponsored a workshop to address Navy requirements for operating in an Ice-Free Arctic Ocean. On these longer time scales, models are currently the only viable way of forecasting future sea ice changes. However, the NIC sea ice charts [3] and passive microwave data [9] serve as an important ongoing source of data for assessing the skill of these forecasts.

Monthly and seasonal forecasts of sea ice concentration and the opening of shipping lanes is also critical to strategic planning for ship operations in ice-covered waters. The NIC currently provides seasonal outlooks for areas of Navy operational interest. Properly scheduling the annual departure of the supply ship for Thule Air Base, Greenland, so that ship is not impeded or turned back by sea ice, is a contemporary example of the important role that good seasonal sea ice forecasts can have on Navy operational activities. The NIC uses a) a simple linear relationship between ice thickness, ice extent, and persistence of antecedent ice conditions, b) a statistical procedure using a pair of pre-season atmospheric pressure indicators to predict favorable or unfavorable summer ice conditions, and c) the use of an analog model which relates large-scale atmospheric forcing patterns with past regional ice anomalies [13]. As always, the NIC sea ice charts, and hence remotely sensed data, play a critical role in every aspect of these forecasts.

Finally, short-term (24-120 hour) sea ice forecasts are also important for tactical operations in ice-covered regions. Currently the NIC relies heavily upon the Polar Ice Prediction System (PIPS) to provide these forecasts [14]. This model is a coupled ocean/ice model forced by the Navy Operational Global Atmospheric Prediction System (NOGAPS) [15]. This model is initialized daily using SSM/I-derived sea ice concentration data and then time-stepped forward to produce 24, 48, 72, and 120-h forecasts. Like the long-term forecasts discussed previously, satellite data provide the only viable way of validating or assessing the skill of these forecasts. One recent satellite validation study [16] showed that for the highly variable month of May, the PIPS forecasts beat a persistence forecast by a statistically significant margin.

V. NEW DIRECTIONS

In this study, we have briefly discussed the current uses of remotely sensed data for Navy operational sea ice analyses and forecasting. The NIC, however, is in constant search of new technology that will ensure the highest quality and most timely release of sea ice products to the fleet. The recent launch of active microwave (scatterometers) and advanced VIS/IR sensors aboard NASA research and development satellites offer new opportunities for improving operational sea ice products and services. The soon-to-launch Navy Windsat-Coriolis mission will carry a passive polarimetric microwave sensor [17] that has not previously flow in space, but builds on the long heritage of the Navy SSM/I sensor. It will undoubtedly play an important role in shaping the future of operational sea ice mapping. Finally, after many years of dedicated service, the PIPS forecast system is undergoing a much-needed facelift. Critical to this new development is the addition of sea ice data assimilation module [18], which is expected to greatly improve the skill of short-term forecasts. The NIC has a small science team dedicated to bringing new technologies to the forefront of operational sea ice analysis and forecasting. This team continues to solicit new ideas from the academic research community that will improve U. S. Navy operational sea ice products and services.

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